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RapidArc radiotherapy planning for prostate cancer: Single-arc and double-arc techniques *vs.* intensity-modulated radiotherapy

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ABSTRACT

RapidArc is a novel technique using arc radiotherapy aiming to achieve intensity-modulated radiotherapy (IMRT)-quality radiotherapy plans with shorter treatment time. This study compared the dosimetric quality and treatment efficiency of single-arc (SA) *vs.* double-arc (DA) and IMRT in the treatment of prostate cancer. Fourteen patients were included in the analysis. The planning target volume (PTV), which contained the prostate gland and proximal seminal vesicles, received 76 Gy in 38 fractions. Seven-field IMRT, SA, and DA plans were generated for each patient. Dosimetric quality in terms of the minimum PTV dose, PTV hotspot, inhomogeneity, and conformity index; and sparing of rectum, bladder, and femoral heads as measured by V70, V-40, and V20 (% of volume receiving >70 Gy, 40 Gy, and 20 Gy, respectively), treatment efficiency as assessed by monitor units (MU) and treatment time were compared. All plan objectives were met satisfactorily by all techniques. DA achieved the best dosimetric quality with the highest minimum PTV dose, lowest hotspot, and the best homogeneity and conformity. It was also more efficient than IMRT. SA achieved the highest treatment efficiency with the lowest MU and shortest treatment time. The mean treatment time for a 2-Gy fraction was 4.80 min, 2.78 min, and 1.30 min for IMRT, DA, and SA, respectively. However, SA also resulted in the highest rectal dose. DA could improve target volume coverage and reduce treatment time and MU while maintaining equivalent normal tissue sparing when compared with IMRT. SA achieved the greatest treatment efficiency but with the highest rectal dose, which was nonetheless within tolerable limits. For busy units with high patient throughput, SA could be an acceptable option.

Introduction

Radical radiotherapy has played an important role in the treatment of localized prostate cancer. Although the total radiation dose to the prostate has been shown to be important for disease control, dose escalation has been limited by known toxicity.[1–3] Intensity-modulated radiotherapy (IMRT) uses multiple fixed treatment fields with highly irregular radiation intensity patterns to deliver exceedingly conformal radiation distributions. Its ability to escalate the total dose while minimizing radiation exposure to surrounding organs has revolutionized the radiotherapy technology in the treatment of prostate cancer.[4–6] Since its introduction in the 1990s, IMRT has rapidly become the technique of choice for prostate cancer in modern radiotherapy centers.

IMRT requires a relatively longer treatment time, leading to more patient discomfort, lower machine throughput, and higher dose delivery uncertainty because of intrafractional organ motion. The large number of monitor units (MU) also raises concern about secondary malignancies after curative treatment due to the exposure to more leakage radiation.[7]

In recent years, arc-based IMRT has been developed to deliver radiotherapy more efficiently.[8–10] RapidArc is a novel treatment planning and delivery method used by Varian Medical Systems (Palo Alto, CA) using intensity-modulated arc therapy technique. Radiation dose is delivered in a single- or multiple-gantry rotations with simultaneously varying shape of aperture created by dynamically moving multileaf collimator, variable dose rate, and gantry rotation speed. It has gained enormous interest because of its potential in delivering IMRT-quality dose distribution with significantly shortened treatment time and lower number of MU. Several recent studies have reported the use of arc-based IMRT delivery methods in prostate cancer.[11–16] Although shortened treatment time is a common finding, there are inconsisten-

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Table 1
Dose specification for target volumes and OAR

CTV	Minimum ≥76 Gy
PTV	<2% volume receives ≥83.6 Gy
	≥98% volume receives ≥76 Gy
	Global maximum dose must be within PTV
Rectum	<20% volume receives ≥70 Gy
	<50% volume receives ≥50 Gy
Bladder	<30% volume receives ≥70 Gy
	<50% volume receives ≥55 Gy
Each femoral head	<5% volume receives ≥50 Gy

cies in the dosimetric outcome. Attempts have been made to compare single-arc (SA) *vs.* double-arc (DA) technique[13–15] but, again, the results vary between different studies.

Our center has been treating prostate cancer with radiotherapy according to the risk of pelvic lymph node involvement as calculated by the roach formula, *i.e.*, PSA + 10(Gleason Score − 6). Any value <15% is regarded as low risk and in such cases, only the prostate and the proximal seminal vesicles will be irradiated. We also do not irradiate the pelvic nodes if there are other clinical considerations. In this article, we compared the performance of IMRT, SA RapidArc, and DA RapidArc in the treatment of prostate cancer without pelvic lymph node irradiation.

Methods and Materials

Fourteen consecutive patients with localized prostate cancer were treated with external-beam irradiation to the prostate and proximal seminal vesicles only with radical intents. Treatment plans using IMRT, SA, and DA were developed for this comparative study.

Treatment planning was performed with Eclipse treatment planning system (Version 8.6; Varian Medical Systems) using a 6-MV photon beam on a Varian c-linac IX linear accelerator. All patients were simulated in supine position with full bladder and immobilized with Alpha-cradle. Computed tomography (CT) scans were acquired with 3-mm slice thickness through prostate and seminal vesicles and 1 cm through other regions. The clinical target volume (CTV) was defined as the prostate gland and the proximal 1-cm seminal vesicles. The planning target volume (PTV) was created by expanding the CTV with a 1-cm margin except 0.5 cm for the posterior rectal border. Rectum, bladder, and femoral heads were contoured as organs at risk (OAR) based on the CT images, with the rectum starting at the level of ischial tuberosities to the rectosigmoid flexure. Seventy-six grays to be delivered in 38 fractions was prescribed to the PTV. The dose constraints to the OAR were determined based on the Radiation Therapy Oncology Group consensus published in 2009.[17] The plan objectives were summarized in Table 1.

For IMRT, 7 fields modulated with dynamic-multileaf collimator (MLC) at gantry angles of 0°, 51°, 102°, 153°, 207°, 258°, and 309° were used. For SA, one single rotation from 179–181° in counterclockwise direction (Varian IEC scale) was used. The collimator was 30° for all cases. For DA, 1 counter-clockwise arc from 179–181° and another clockwise arc from 230–130° were used. The collimator was between 15 and 30°. Slight individual variations were allowed for range of gantry angle and collimator rotation to achieve the best target coverage and sparing of critical structures. Dose calculation was performed using the Anisotropic Analytical Algorithm. The optimization parameters for both IMRT and RapidArc were listed in Table 2. Two pseudo structures, Blad-O (bladder minus PTV with extra 3-mm margin) and Rectum-O (rectum minus PTV with extra 3-mm margin) were generated for optimization. The smooth parameters for dynamic MLC segmentation were set to 20. Treatment position was verified with Varian On-Board Imager using orthogonal kilovoltage images.

Parameters chosen for comparison included the mean dose, the maximum and minimum doses, the conformity index (CI = $V_{Dprescribed}/V_{PTV}$) and the inhomogeneity index (II = (D(5% PTV) − D(95% PTV))/Dmean) within the PTV. Radiation exposure of the rectum and bladder to high-, medium-, and low-dose levels were assessed by the percentage volumes receiving at least 70 Gy (V70), 40 Gy (V-40), and 20 Gy (V20), respectively. The V-40 of each femoral head was also compared. The MU and the treatment time, which includes the beam-on time and the transition time between radiation fields, were used to evaluate the efficiency of treatment delivery. Integral dose excluding the dose to the PTV was also included in the comparison.

Student's *t*-test was applied for the statistical analysis.

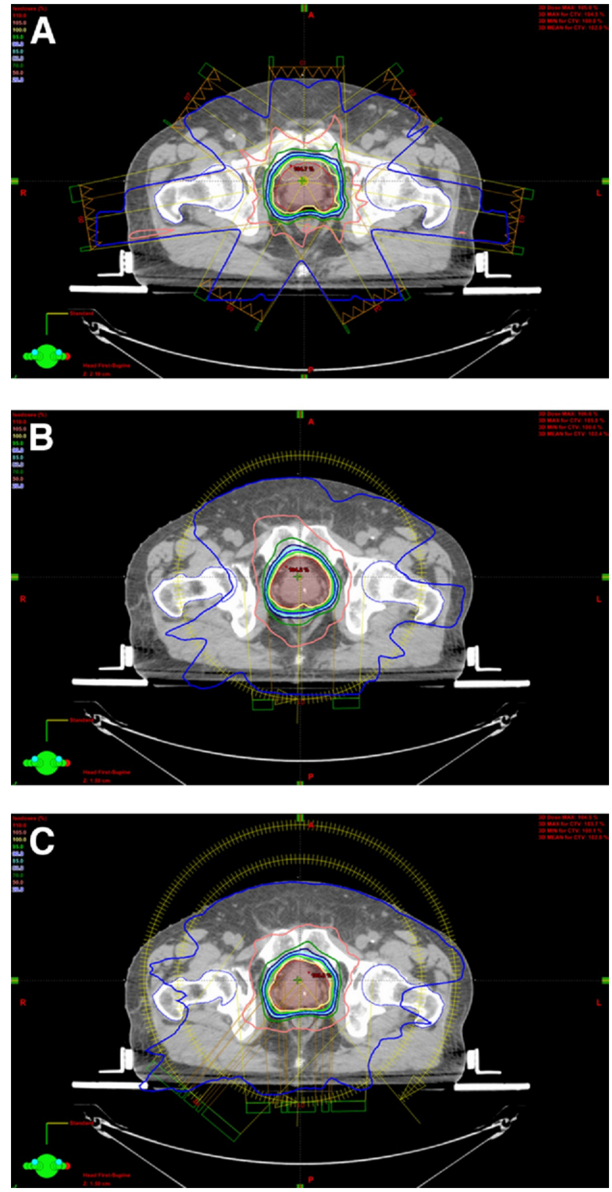

Fig. 1. Dose distributions for all approaches of a typical patient. (A) IMRT; (B) SA RapidArc; (C) DA RapidArc.

Table 2
Optimization parameters for both RapidArc and IMRT

Structure	Volume (%)	Dose (Gy)	Priority
Body	0	78	400
CTV	0	77	50
PTV	0	78	100
	100	76.5	100
Blad-O	15	55	50
	25	50	50
	35	45	50
	50	40	50
	0	78	50
Rectum-O	15	40	50
	25	35	50
	35	30	50
	50	25	50
	0	78	50

Two pseudo-structures, Blad-O and Rectum-O are for optimization. Blad-O = bladder minus PTV with extra 3-mm margin; rectum-O = rectum minus PTV with extra 3-mm margin.

Results

The mean volume of PTV was 142 mL (range, 77–232 mL). All plan objectives were met satisfactorily by IMRT, SA, and DA techniques. The typical dose distributions are shown in Fig. 1.